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IMAGE ANALYSIS RESEARCH

PROJECT 6607

QUARTERLY REPORT

Period: June 1, 1968 through August 31, 1968

by

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TABLE OF CONTENTS

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I INTRODUCTION

This program was undertaken to investigate the occurance of systematic errors in the taking of measurements of small objects from high resolution reconnaissance photography. Small object size in this situation means objects from two to ten or fifteen resolution elements in size, with primary emphasis being placed on original material in the 70 to 90 lines/mm resolution range, (as read from low contrast three-bar targets.)

As a working hypothesis, the error in the measurement of a small object for a given object size, shape, contrast, and exposure level can be stated as:

$$E = \overset{(1)}{K} + \overset{(2)}{\sigma_F} + \overset{(3)}{\sigma_m}$$

where E = total error

K = systematic error for the given conditions.

σ_F = error due to the random nature of the granularity pattern of the film.

σ_m = error in performing the measurement (operator error)

The total error for a measurement is the sum total of all these error factors. The K is the error attributed to the non-linear effects of the film, and one of the primary objectives of this study is the quantitative measurement of this systematic error, and also the development of techniques to correct for this source of error. Unfortunately, this error cannot be completely isolated from other sources of measurement error. Some error will be due to the random structure of the film itself, since it consists of patterns of grain. However, this error can be estimated by replicating the experimental material, holding all experimental parameters as constant as possible. In practice, this means taking a series of photographs with the maintenance of identical exposure, processing, and target conditions, and then measuring the variation of the total measurement error after taking out the variance of repeated measures on the same image. This will provide an estimate of the variation caused by the film itself.

Another source of error is the error due to the measurement taking process itself. The significance of this error can be established by taking repeated measurements on the same film material, and computing the confidence limits about the mean reading. Relatively narrow limits mean that the reading on a particular object can be repeated with good accuracy, even though the total error may be large. (The total error is easily computed by taking the difference between the actual reading and the expected size, where the expected size is determined by the scale reduction and target size).

As noted previously, the error factor K is defined under constant conditions of exposure, processing, etc. However, in its most general form, this error is a functional relationship dependent on these other parameters. That is:

$$K = f(D, \Delta D, S, S_h, P, S_y)$$

where D is defined as the average density of the background.

ΔD is the contrast of the object under consideration.

S is the size of the object.

S_h is the shape of the object.

P is the processing conditions of the material.

S_y is the performance level of the taking system.

For maximum usefulness of the results of this study, the relationship of the error to these parameters should be examined. This may permit some generalizations to be made about the nature of the error, and also reduce the total amount of data required to evaluate the error under all conditions.

The data existing under a previous study 25X1 Project 6501) is adequate to permit the examination of all these parameters except taking system performance. (All previous exposures were made using the taking system as a constant parameter.)

The program has been divided into four tasks. These are:

(1) The establishment of confidence limits utilizing material presently available (from Project 6501). This is essentially the examination of error in performing the measurement, which was designated σ_m.

(2) Generation and evaluation of a set of replicate data, using two targets and two exposure levels. This task is essentially the determination of the film error, that is, σ_F since all conditions are to be held as constant as possible in the generation of the replicate material.

(3) Generation and evaluation of a set of replicate data made with the taking system lens stopped down to yield a performance level of approximately 60 lines/mm. This set of data will yield data on the variation of mensuration error as a function of system performance.

(4) The analysis of the data generated under tasks (1), (2), and (3). In particular, the relationship of the measurement error to parameters of importance will be analyzed, and techniques for the utilization of the data in operational situations will be developed.

The results of task (1) only will be covered in this report, since the remainder of the tasks are to be accomplished later in the program.

II TECHNICAL DISCUSSION

As noted previously, the first phase of this program involves the analysis of the error in making repeated measurements on the same object. The criteria used in the determination of this error is the confidence interval about the computed average value.

The error in a measurement is defined as:

Average error = Average measured size - expected size

where

Expected size = (Actual size on target)/(Scale factor of photographic system).

If a set of N measurements is taken on an object, the confidence interval for the mean is obtained through the following steps:

The mean is computed by $\bar{x} = \sum_{i=1}^{N} x_i$ and sample variance is computed by $S^2 = \sum_{i=1}^{N} (x_i - \bar{x})^2/(N-1)$

where x_i is the i^{th} measured size of an object.

N is the total number of measurements

The standard error $S_{\bar{x}}$ is defined as: $S_{\bar{x}} = S/\sqrt{N}$, and the confidence interval is computed as:

confidence interval = $\bar{x} \pm t_{\alpha} S_{\bar{x}}$

where t_{α} is obtained from the Student's t table for N-1 degrees of freedom and for the desired confidence level.

The 95% confidence level was used for all computations on the data. All the material from Project 6501 in which multiple readings were made was analyzed. Figures 1 through 3 show the typical results obtained. The number of images on which multiple readings had been made was only about fifteen, so the quantity of data on which confidence intervals could be computed was not as large as desired, but more data will be available shortly to confirm the trends that have been observed.

The following tentative conclusions have been drawn based on the available data:

1) The measurements on single bars are consistantly larger than the expected size, and the confidence intervals do not include the zero error line. This indicates that consistant corrections could be made for this type of object. (See Figure 1) The confidence intervals are between 1 and 2 microns wide, which indicates the operator's repeatability on performing a measurement on this type of

object is very good. The size of the average error ranges from 2 to 10 microns, depending on the size of the bar, and the average density level of the background. The error is considerably larger for detail which is more dense than the background. (See Figure 4.) The confidence intervals are relatively consistant (in absolute microns) over a range of sizes from 100 down to four or five microns.

2) The measurements on circular objects show a smaller average error than that for single bars. The confidence intervals are slightly wider than that for single bars, with the zero error line falling within the confidence interval in many cases. This indicates that the average error is not correctable for many cases, and in fact, may not be required, since the error is relatively small. By observing Figure 2, it can be seen that the average error does not fall on a smooth line from large to small expected sizes. Since one would not normally expect film to cause these kinds of deviations on a consistant basis, the random film error is probably an important effect. Another way of saying this is that the error is not consistant when considering one size object with another, although the measurement of a given size object repeats well, as shown by the small size of the confidence intervals.

This should be verified and repeated in the next set of data available, since measurements will be taken of the same object photographed several times. This same effect can be observed on the error curves for single bars, although the deviations are somewhat smaller.

3) The triangles show the widest variations of the three types, both in terms of the variation of the average error from one point to another, and the size of the confidence interval. The confidence interval ranges from 1.5 to 3 microns wide. It appears that the application of correction factors to measurements of this type of object may not be possible due to the wide variation in the repeatability of the measurements.

4) Figure 4, which is a plot of the average error as a function of the log exposure level for single bars, shows the increasing error

as a function of exposure level. The error generally increases as the exposure level is increased, and this is particularly true for high density detail on a light background. Also, it appears that the use of spray processing causes a consistantly greater error than that observed on the samples that were immersion processed in a Versamat. The data in Figure 4 shows considerable scatter since many points are single measurements. The trends shown by Figure 4 will be examined in more detail when data from multiple readings throughout the range of the D log E curve becomes available.

III FUTURE WORK

The work for the immediate future consists of two primary tasks. These are:

(1) Generation of more sets of data with multiple readings to confirm already available data, and also to permit the closer examination of possible functional relationships between measurement error and contrast, exposure, and detail background.

(2) Examination of the error due to random film effects. This will be done by taking multiple readings on material replicated six times; that is, six images will be used which have been subjected to identical exposure and processing.

(3) A set of material will be made in which the taking system performance is in the 60 lines/mm range. This material will be used to analyze the effects of a different system performance level on measurement accuracy. All future material will be spray processed, with a gamma of 1.7 to 1.8, since this most closely duplicates the operational situation.

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FIGURE 1. AVERAGE ERROR AND CONFIDENCE INTERVALS FOR SINGLE BARS 3404 FILM

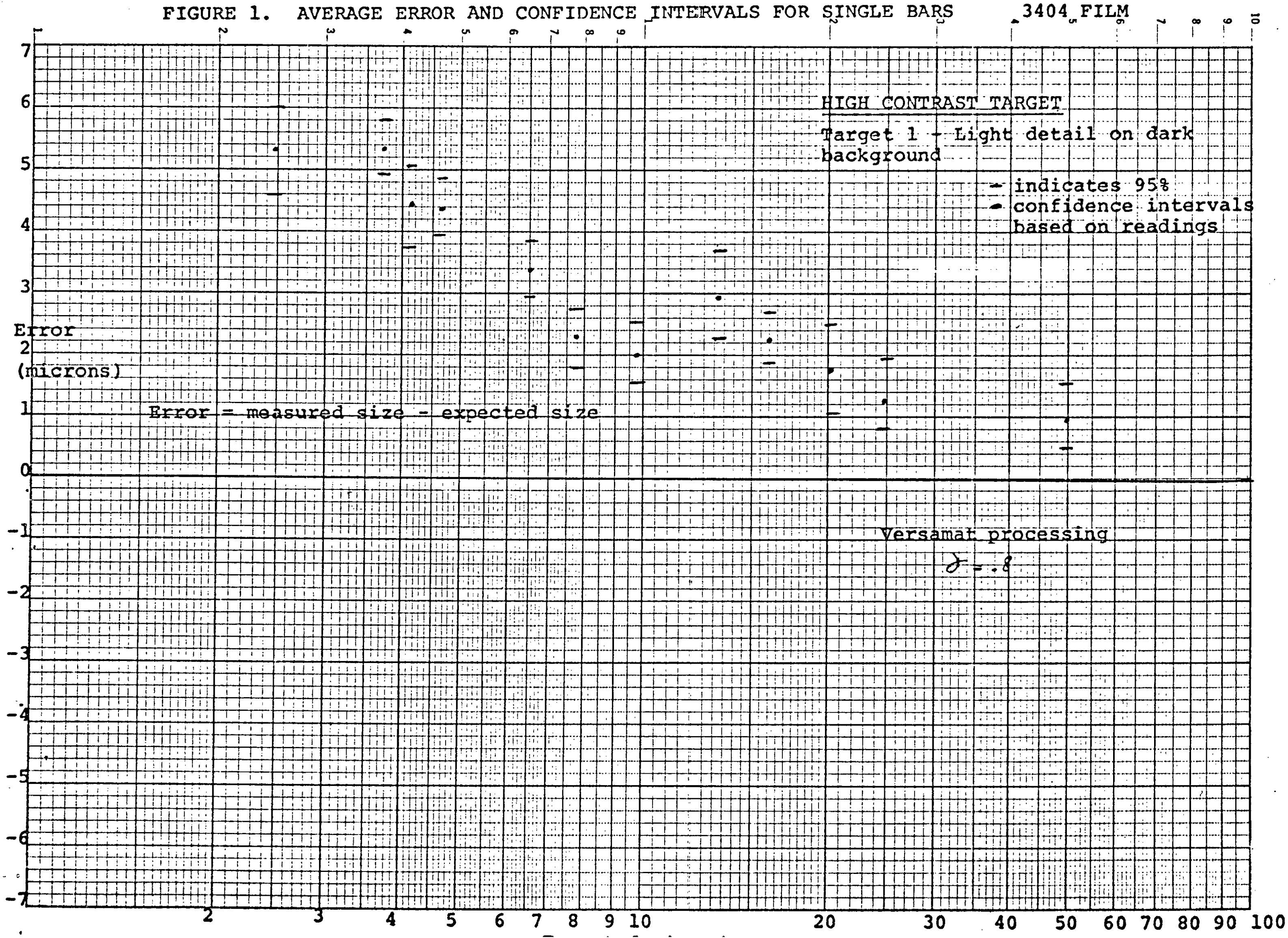

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FIGURE 2. AVERAGE ERROR AND CONFIDENCE INTERVALS FOR CIRCLES 3404 FILM

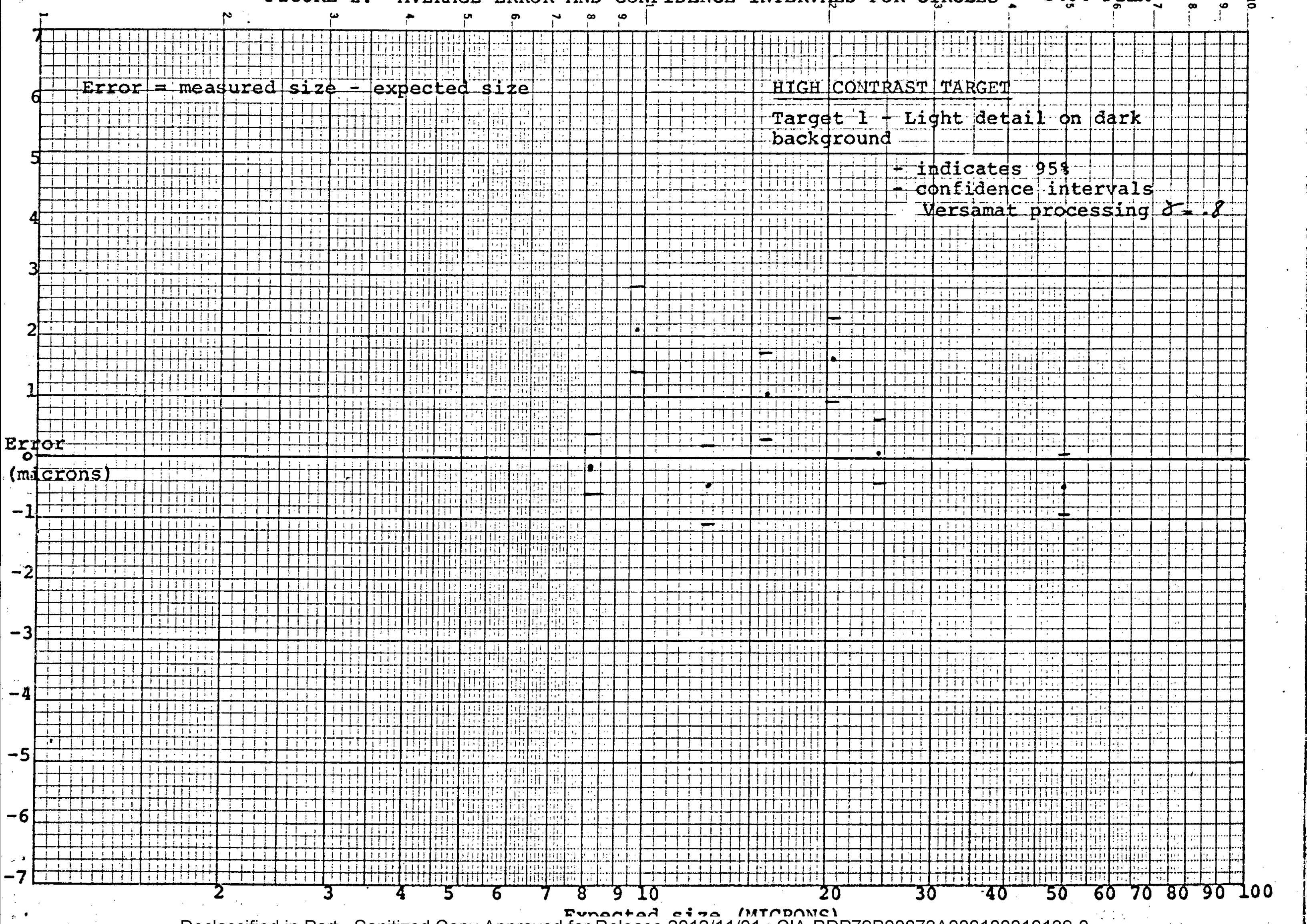

FIGURE 3. AVERAGE ERROR AND CONFIDENCE INTERVALS FOR TRIANGLES 3404 FILM

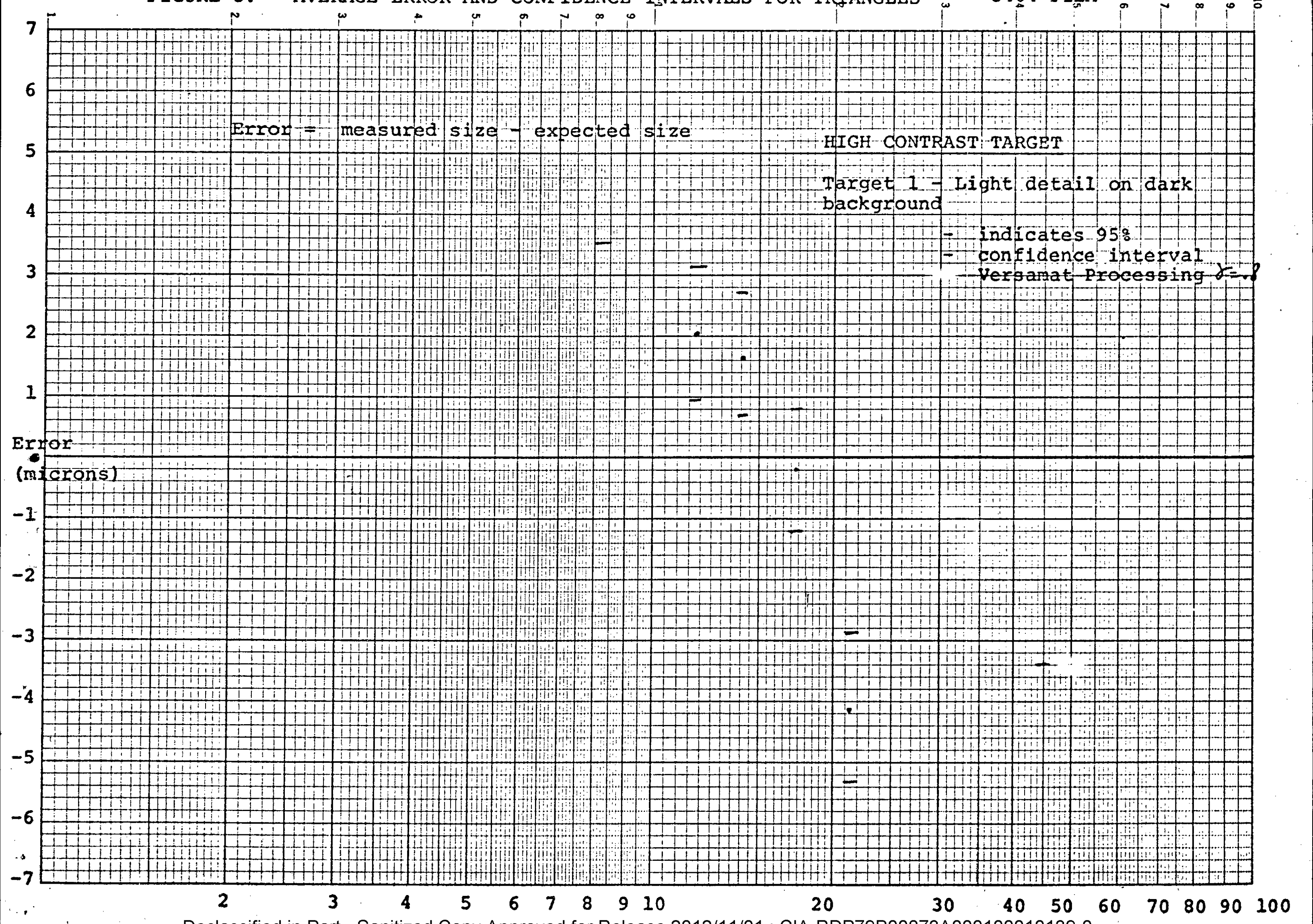

FIGURE 4. COMPARISON OF AVERAGE ERROR vs LOG EXPOSURE FOR SINGLE BARS 3404 FILM